ON-LINE FATIGUE CRACK GROWTH MONITORING IN EXTERNALLY PRESSURISED VESSELS USING THE ALTERNATING CURRENT POTENTIAL DROP (ACPD) TECHNIQUE. *

F. Livingstone and I. M. Kilpatrick
Fatigue Section
Admiralty Research Establishment
Dunfermline, SCOTLAND

INTRODUCTION

At ARE (Dunfermline) fatigue tests are carried out on internally stiffened, welded steel cylindrical pressure vessels. These vessels are constructed from high yield strength quenched and tempered steels with full penetration butt and T-butt welds.

Although subjected to external cyclic pressure, the high tensile residual stresses induced by the welding provides the necessary conditions for fatigue cracking, particularly at the stiffener to pressure shell T-butt weld. Data on crack initiation and propagation is required so that the fatigue performance of the steels, weld consumables, and procedures can be assessed.

A paper presented at the 1982 Review of Progress in Quantitative NDE, described the NDE techniques and inspection procedures used at that time, [1]. This involved periodic interruption of the fatigue test, every 2000 cycles, to allow manual inspection with various NDE techniques, such as MPI, Eddy Current, Ultrasonic Time of Flight Diffraction (ToFD), and ACPD.

During the testing of a small vessel with a single internal stiffener, Fig. 1, approximately 1700 data points were collected from 72 monitoring positions, every 5 degrees around the circumference, on each side of the T-butt weld. The total time taken to complete a fatigue test was about 160 days with only 50 days of actual fatigue cycling. A test is completed when a crack has penetrated through the pressure shell as shown in Fig. 2. It was suspected that the interruptions were affecting the fatigue propagation time to through cracking.

Continuous on-line monitoring was therefore highly desirable not only to reduce overall testing time but also to provide data on the effect of any interruptions to the fatigue cycling. This paper describes the advances made in the application of an on-line crack growth monitoring system using the AC potential drop technique. Data from a series of fatigue tests on simple vessels with single stiffeners, similar to Fig. 1, will be presented. This data illustrates the advances made and the capabilities of the technique.

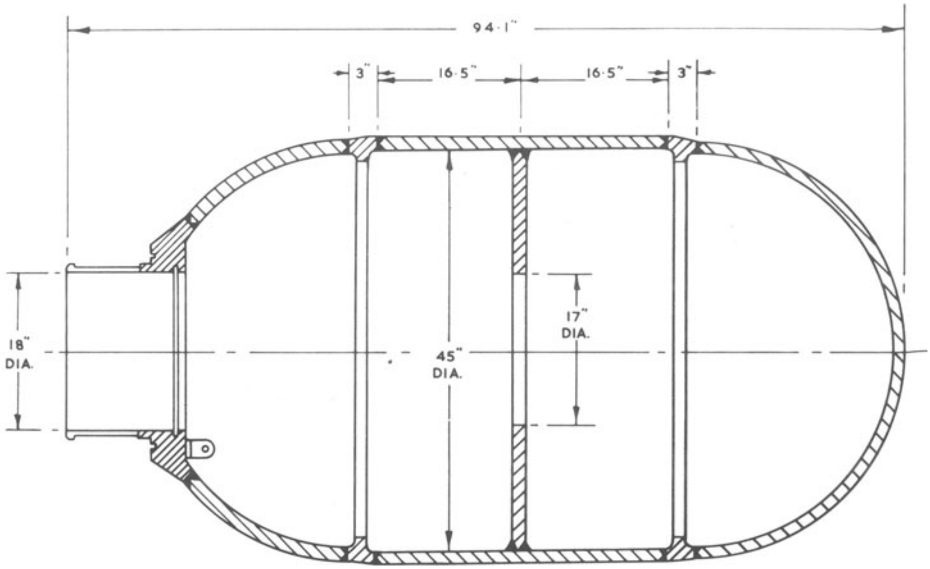

Fig. 1. Small Fatigue Test Vessel.

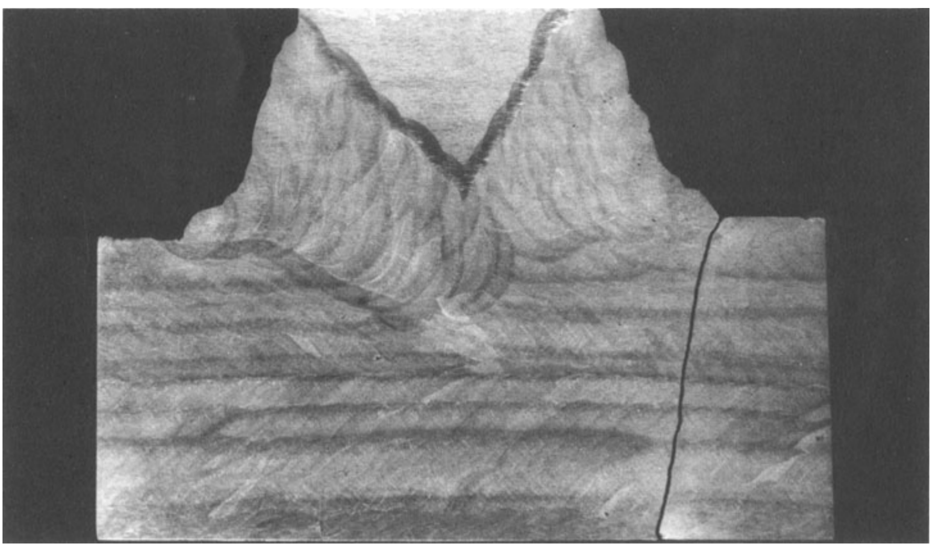

Fig. 2. Through Fatigue Crack.

ACPD TECHNIQUE

The basic principles of the ACPD technique are that the resistance of a structure to an electrical current is changed if a crack or defect is present in the material, linked with the well known 'Skin Effect' of a conductor carrying an alternating current.

In practice a high frequency uniform alternating current in the order of 2 to 5 amps at about 6 kHz is injected into the inspection area of the structure through two field contacts. Due to the skin effect the AC flows near to the surface with a nominal depth, proportional to the material's resistivity and inversely proportional to the materials permeability and to the AC frequency. For mild steel this skin depth is approximately 0.2 mm. If a surface breaking defect exists which has a depth 'a' greater than the skin depth, then the current will flow down one side and up the other. By taking measurements of the potential drop across a known path length, commonly 10 mm, adjacent to and astride the defect, the difference in these measurements is directly proportional to the defect's depth and can be calculated by the simple formula

$$a = [(V1/V0) - 1] \times S/2$$

where a is the defect's depth in mm, V1 is the PD astride the defect, V0 is the reference PD adjacent to the defect, and S is the PD probe spacing in mm, commonly 10 mm. A more detailed explanation of the technique and of the mathematics of the electrical field around a crack has been presented in previous Reviews [2,3,4].

ON-LINE ACPD

Usually the field current is injected into a structure through demountable contacts held in place by magnets, with the PD measurements taken by a hand-probe. However for continuous on-line monitoring permanently attached contacts are required for both field and PD measurements.

An additional problem is introduced by the method used to fatigue cycle the test vessels, known as 'Soft cycling'. This means that the on-line ACPD has to operate underwater while subjected to fluctuating pressures of several hundred bar. Access for cables during cycling is through watertight glands with the ACPD instrument positioned approximately 12 metres from the inspection sites.

In the early on-line monitored vessels, (pre '83), a very simple style of contact and glanding was used. The on-line data obtained, Fig. 3, is very erratic and bears no relationship to the manual hand-probe results, which show the expected increase in crack depth with increasing number of cycles. Both the design of the gland and the style of contacts were suspected of introducing errors, due to induced voltages, high resistances, or even stray capacitive pick up.

WATERTIGHT GLANDS

The initial glands, although capable of withstanding the high pressures, were basic in electrical design, Fig. 4, creating very large inductive loops with relatively high connection resistances. A sequence of improvements were carried out and the final design, Fig. 5, has greatly improved the electrical performance due to the use of twisted enamelled wires and precision electrical connectors, gold on gold contacts. Twisting wires creates a series of small loops, the inductive voltage of which when in a changing magnetic field tend to cancel. This design of gland has been successfully pressure tested to well in excess of the fatigue test pressure.

ON-LINE CONTACTS

The original style of contacts were produced by soldering the ACPD leads to pieces of steel shim, which were then spot welded into place at the desired monitoring position, Fig. 6. The basic problems with this style of contact are that it does not provide an accurate path length for

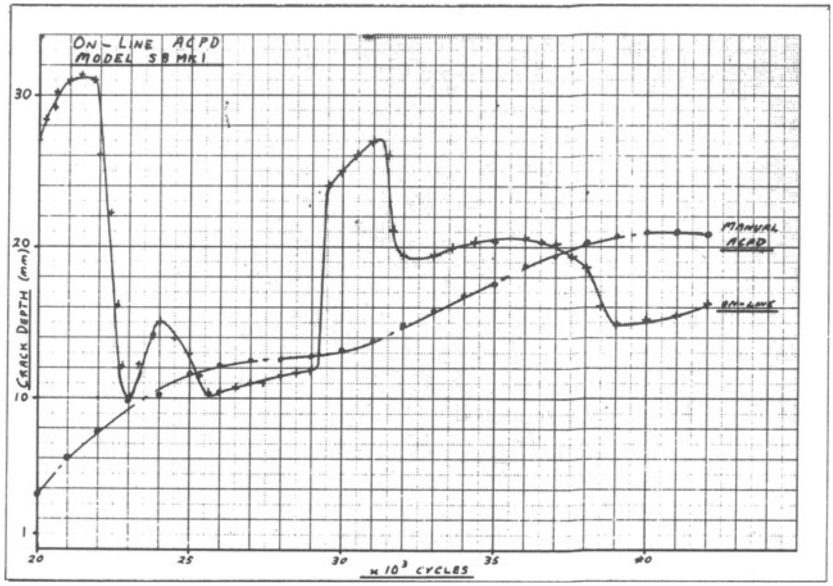

Fig. 3. On-line data from first continuously monitored test vessel, with corresponding manual hand-probe data

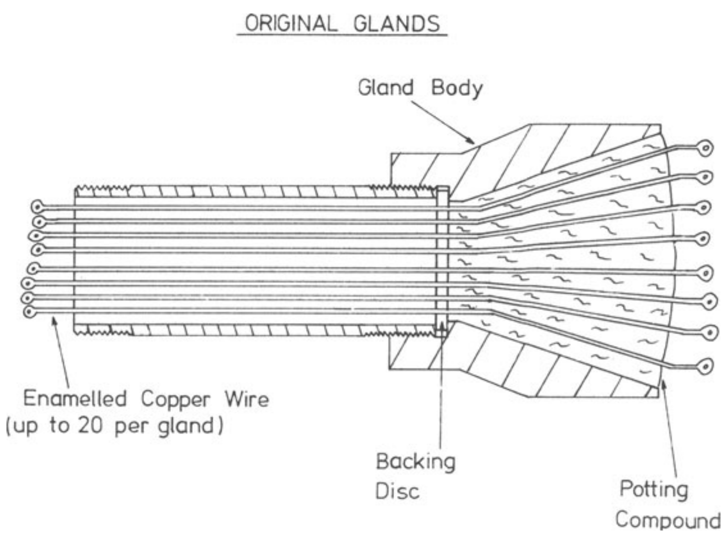

Fig. 4. Original design of watertight glands.

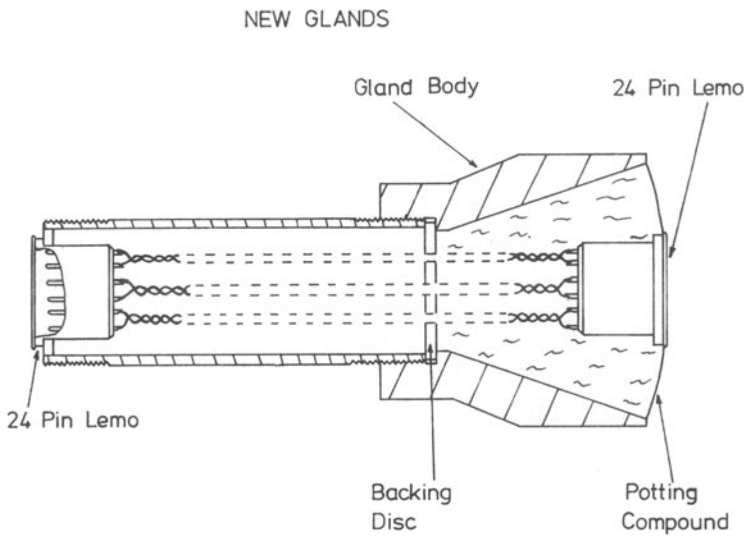

Fig. 5. Final design of watertight glands. Improved electrical performance.

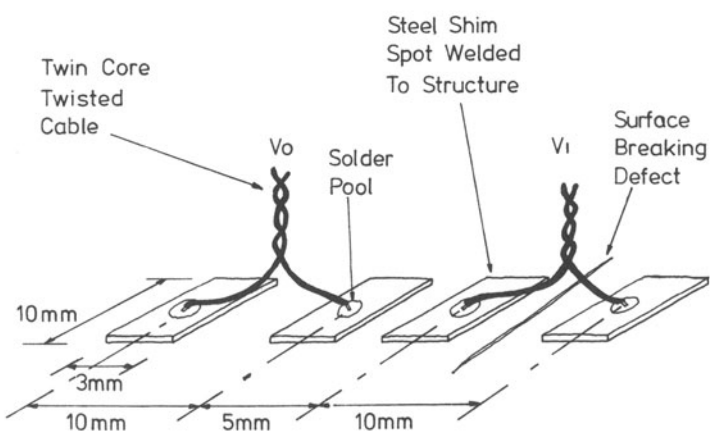

Fig 6. Original style of ACPD contact.

the PD measurements. It also creates an inductive loop between the measuring leads and the plate surface. The best style of contact was found to be produced by soldering the ACPD cables onto 1 mm diameter, plain steel pins. These pins are then cropped and spot welded in place producing a very strong contact with minimum inductive loop, Fig. 7. To ensure accurate path lengths are achieved when spot welding, the pins are passed through holes in a thin plastic strip. This strip can be moulded into the contours of the surface, giving accurate path lengths even on bad weld profiles.

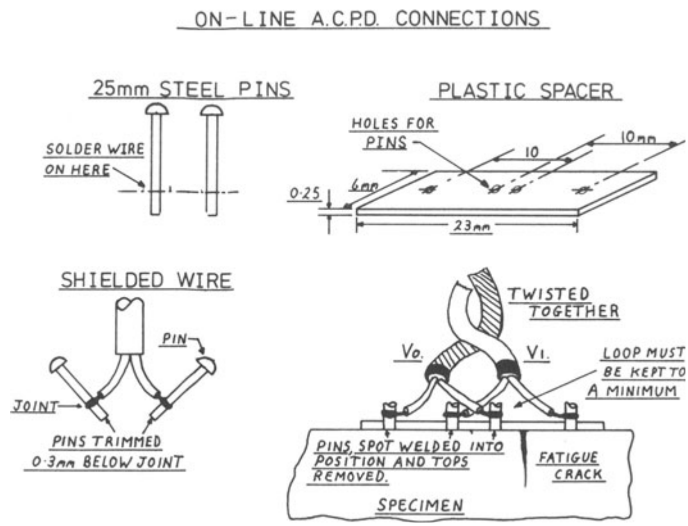

Fig. 7. Final style of contact using 1 mm steel pins.

RESULTS OF IMPROVEMENTS

These modifications were all carried out during the life of one test vessel and crack growth data obtained is shown in Fig. 8. Here the on-line data closely follows the hand-probe results and both show the expected increase in crack depth with increasing number of cycles.

In the next series of fatigue tests a pressure signal was used to ensure that the PD measurements were taken under conditions of maximum crack opening. On-line data from 3 monitoring positions in the last

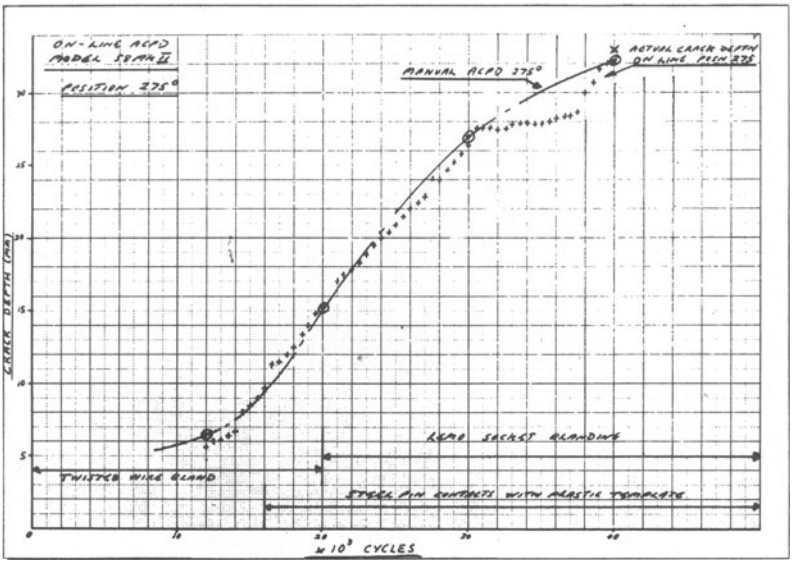

Fig. 8. Data from test vessel with modifications to ACPD on-line.

vessel tested are shown in Fig. 9. Crack initiation and crack growth rates can easily be determined from the data, where as before initiation could only be determined to within the NDE inspection interval.

The increased performance of the on-line monitoring system now allows the effect of any interruption to the fatigue cycling to be identified. This effect can be seen in Fig. 9, but is shown more clearly in Fig. 10. This shows portions of the data obtained from the last 2 pressure vessel tests around the period of interruptions for total NDE analysis. It can be clearly seen that after an interruption there is an extension of the

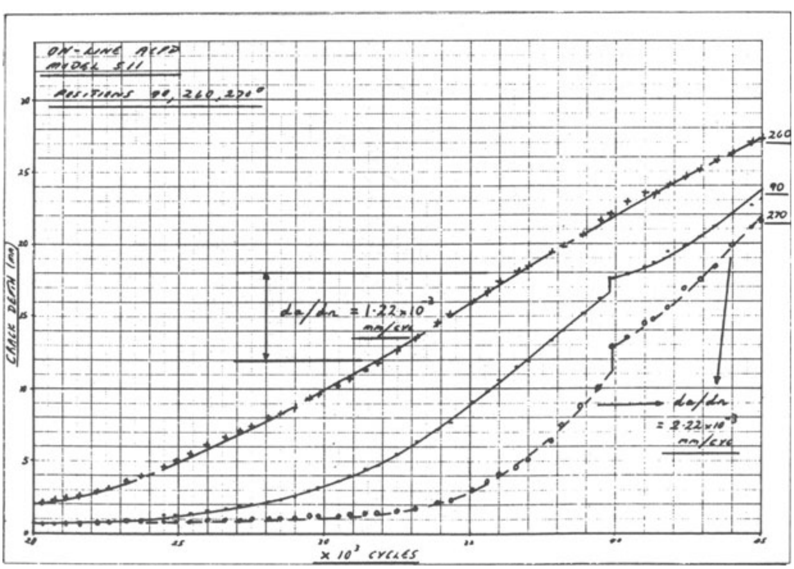

Fig. 9. On-line data from latest test vessel.

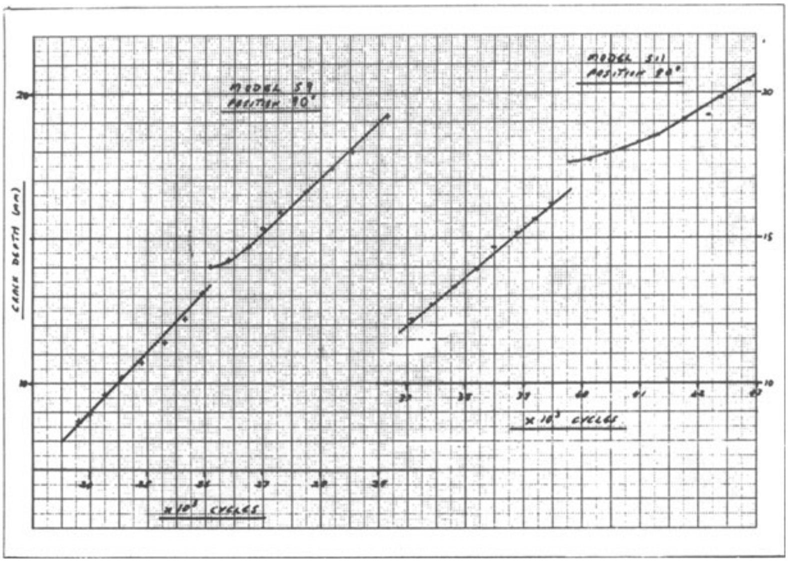

Fig. 10. Portion of data from last 2 tests indicating effect of interruptions.

crack, followed by a period where the crack is re-establishing its preferred growth rate.

The accuracy of the depth measurements taken from the on-line ACPD system, has been determined by comparison to optical measurements and to the ToFD records from all vessels tested up to date. This has shown that an accuracy to within 0.75 mm can be expected.

CONCLUSIONS

The on-line ACPD monitoring system described can successfully:

1. Operate underwater while subjected to high pressures.
2. Indicate crack initiation.
3. Size cracks to within 0.75 mm.
4. Provide data on crack growth rate.
5. Identify effects of interruptions to the fatigue cycling.
6. Monitor crack closure/opening during fatigue cycling.

FUTURE DEVELOPMENTS

A computer controlled submersible multiplexing unit, which should withstand the high pressures is being developed at the moment. This unit will overcome the restrictions imposed by the glanding, which limit the number of monitoring positions to 18. It is expected with the multiplexing unit to cover all monitoring positions within a single stiffened vessel, (144 positions), with only 16 control lines. This unit could be positioned up to 20 m from the inspection sites with a further 20 m run to the host computer and ACPD instrument. Greater distances could be achieved by installing a pre-amp within the multiplexing unit.

Producing the on-line contacts of the style described in large numbers would be time consuming and would require QA on the production. Development of a contact system similar to weldable strain gauges is envisaged.

A study into the effect of interruptions in the fatigue cycling is being carried out at the moment. It is known that this effect is dependent on the length of time of the interruption.

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